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Title:

REGULATOR CIRCUIT FOR INDEPENDENT ADJUSTMENT OF PUMPS  
IN MULTIPLE MODES OF OPERATION

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## REGULATOR CIRCUIT FOR INDEPENDENT ADJUSTMENT OF PUMPS IN MULTIPLE MODES OF OPERATION

### FIELD OF THE INVENTION

[0001] The present invention relates generally to memory devices and,  
5 more particularly, to a voltage regulator circuit for the independent adjustment  
of pumps in multiple modes of operation of the memory device.

### BACKGROUND OF THE INVENTION

[0002] A semiconductor device may be designed for any of a wide  
variety of applications. Typically, the device includes logic circuitry to receive,  
10 manipulate or store input data. The circuitry subsequently generates the same or  
modified data at an output terminal of the device. Depending on the type of  
semiconductor device or the circuit in which it is used, the device typically  
includes circuits which provide internal power signals that are regulated to be  
substantially independent of fluctuations in the externally generated power input  
15 signal(s).

[0003] An example of a data storage or memory device having such  
internal power signal circuits is the DRAM (dynamic random access memory).  
Conventionally, the DRAM receives an external power signal ( $V_{ccx}$ ) having a  
voltage intended to remain constant, for example, at 4.5 volts measured relative  
20 to ground. Internal to the DRAM, the power regulation circuit maintains an  
internal operating voltage signal ( $V_{cc}$ ) at a designated level, for example, 2.5  
volts. Ideally,  $V_{cc}$  linearly tracks  $V_{ccx}$  from zero volts to the internal operating  
voltage level, at which point  $V_{cc}$  remains constant as  $V_{ccx}$  continues to increase  
in voltage to the designated  $V_{ccx}$  level.

25 [0004] DRAMs also typically include a regulated constant pumped  
supply voltage ( $V_{ccp}$ ) which is greater than  $V_{cc}$ , for example, four volts.

Conventionally, the pumped voltage drives the word lines of a DRAM. The DRAM has memory arrays consisting of a number of intersecting row and column lines of individual transistors or memory cells. The pumped voltage needs to be greater than  $V_{cc}$  to ensure that memory access operations, such as a memory cell reads or writes, are performed both completely and quickly. Ideally,  $V_{ccp}$  does not fluctuate. If  $V_{ccp}$  is too high, damage to the memory cells may result. If it is too low, the memory chip may have poor data retention or may otherwise operate incorrectly.

[0005] The pump used to create the pumped voltage is typically referred to as a  $V_{ccp}$  pump. In addition to the  $V_{ccp}$  pump, a pump regulator is required and an oscillator may be used to ensure that the pumped voltage  $V_{ccp}$  falls within the desired limits described above. The most common oscillator used in the  $V_{ccp}$  pump is a standard CMOS (complementary metal oxide semiconductor) ring oscillator. A unique feature of the standard CMOS oscillator is its multi-frequency operation due to its multiplexed circuitry and various oscillator tap points. The oscillator is controlled by a control signal generated by the pump regulator. Whenever the pump regulator issues a pump enable control signal, the oscillator becomes functional and the pump becomes operative.

[0006] FIG. 1 illustrates a conventional pump regulator circuit 10. The regulator circuit 10 includes a step down resistance 12, a voltage divider circuit 20, voltage adjustment circuit 40 and a level detect circuit 14. The step down resistance 12 is connected to the pumped voltage  $V_{ccp}$ , which is input from a  $V_{ccp}$  pump (not shown). The step down resistance 12 is illustrated as a resistor, but it should be appreciated that the resistance 12 could consist of multiple resistors, transistors, diodes, any combinations of these elements or any

other circuit element that would cause the pumped voltage  $V_{ccp}$  to drop by a specified voltage amount.

[0007] The voltage divider circuit 20 is connected between the step down resistance 12 and another voltage (illustrated as a ground potential). The illustrated voltage divider circuit 20 includes a plurality (e.g., five) of series connected n-channel MOSFET (metal oxide semiconductor field-effect transistor) transistors 22, 24, 26, 28, 30. Each transistor 22, 24, 26, 28, 30 has its gate connected to a voltage such as  $V_{cc}$  such that they are always in the active state. In addition, each transistor 22, 24, 26, 28, 30 is typically a long "L" device that causes a relatively small current draw when activated (i.e., it is well known in the art that the amount of current a MOSFET can carry is proportional to  $W/L$ , where  $W$  is the width of the transistor and  $L$  is its gate length). Thus, if there were no other elements in the circuit 10, the resistance 12 and the voltage divider circuit 20 would divide the pumped voltage  $V_{ccp}$  in accordance with their resistances and cause a predetermined reference voltage  $V_{ref}$  to appear at node A. It should be noted that the voltage divider circuit 20 may comprise other elements besides the illustrated transistors 22, 24, 26, 28, 30 and it should be appreciated that the circuit 20 could consist of multiple resistors, transistors, diodes, any combinations of these elements or any other circuit element that would create resistance effecting the voltage in a desired manner.

[0008] The reference voltage  $V_{ref}$  is input into the level detect circuit 14. The circuit 14 can be any conventional circuit and thus, the internal circuitry of the level detect circuit 14 is not shown for convenience purposes. As is known in the art, in operation the typical level detect circuit 14 inputs the reference voltage  $V_{ref}$  (sometimes referred to as a normalized voltage) and compares it to a threshold voltage, which when exceeded, provides a signal to turn off the pump. Similarly, if the reference voltage  $V_{ref}$  is less than the threshold, the circuit 14

provides a signal that turns on the pump. This is typically done by feeding the reference voltage into a modified inverter stage having an adjustable trip point. The trip point is modified with feedback to provide hysteresis for the circuit 14. Subsequent inverter stages provide additional gain and boost the reference voltage signal to the full CMOS level necessary to enable or disable the oscillator. Minimum and maximum operating voltages for the Vccp pump are controlled by the first inverter stage trip point, hysteresis and diode connected transistors voltages.

[0009] The output of the level detect circuit 14 is a pump on/off signal. The pump on/off signal is used as a control signal for the oscillator (not shown) connected to the Vccp pump. Whenever the pump on/off signal is set to a value indicating that the Vccp pump should be enabled, the oscillator becomes functional and enables the pump.

[0010] There is a need for the regulator circuit 10 to operate based on different operating voltages (e.g., Vcc) and pumped voltages (e.g., Vccp). The different voltages may be required, for example, because a particular system has a manufacturing specification mandating specific operating and pumped voltages. Accordingly, the regulator circuit 10 typically includes the adjustment circuit 40 to adjust the voltage divider circuit 20 so that the proper pump on/off signal PUMP ON/OFF can be generated regardless of the Vcc and Vccp voltage levels.

[0011] The adjustment circuit 40 includes a plurality (e.g., five) of n-channel MOSFET transistors 42, 44, 46, 48, 50. Each transistor 42, 44, 46, 48, 50 has their source and drain terminal connected across the source and drain terminal of a respective voltage divider transistor 22, 24, 26, 28, 30. Unlike the gate terminals of the voltage divider transistor 22, 24, 26, 28, 30, the gate terminals of the adjustment transistors 42, 44, 46, 48, 50 do not have to be connected such that they are always in the active state. Instead, the gate of each

adjustment transistor 42, 44, 46, 48, 50 can be connected such that the transistor 42, 44, 46, 48, 50 is active or inactive.

[0012] For example, in FIG. 1, the fourth and fifth adjustment transistors 48, 50 are connected to a voltage such as  $V_{cc}$ , which activates both transistors 48, 50. With both of these adjustment transistors 48, 50 in the active state, their corresponding voltage divider transistors 28, 30 are shunted. This, removes the resistances associated with the fourth and fifth voltage divider transistors 28, 30, which changes the voltage divider circuit 20 and alters the voltage level of the reference voltage  $V_{ref}$ . Thus, the adjustment transistors 48, 50 act as switches that can switch in or out (i.e., do not shunt or shunt) the resistance associated with their corresponding voltage divider transistors 28, 30.

[0013] As noted above, the other adjustment transistors 42, 44, 46 do not have to be connected such that they are always in the active state either. For example, the first three adjustment transistors 42, 44, 46 are connected to two signal lines OPT1, OPT2. The signal lines OPT1, OPT2 can be set by test keys, fuses or any other manner such that their respective adjustment transistors 42, 44, 46 are active or inactive. If any of these adjustment transistors 42, 44, 46 are set to the active state, then their corresponding divider transistor 22, 24, 26 will be shunted. Likewise, if any of the first three adjustment transistors 42, 44, 46 are set to the inactive state, then their corresponding divider transistor 22, 24, 26 will not be shunted. Thus, for the illustrated regulator circuit 10, depending on how the signal lines OPT1, OPT2 are set, the voltage divider circuit 20 may include none, all three or some of the first three divider transistors 22, 24, 26 (i.e., in FIG 1 the fourth and fifth divider transistors 28, 30 have already been shunted and thus, only the first three divider transistors 22, 24, 26 can add resistance to the divider circuit 20).

[0014] Thus, depending upon the manufacturing specifications of the memory circuit utilizing the pumped voltage  $V_{ccp}$  and the regulator circuit 10, the adjustment circuit 40 can be configured such that the voltage divider circuit 20 generates the proper reference voltage  $V_{ref}$ . Typically, the regulator circuit 10 controls the oscillator such that it is operated at a higher frequency when the DRAM is in a power-up operating mode than in nominal operation because this will assist the  $V_{ccp}$  pump in initially charging DRAM components such as load capacitors. There is a third operating mode that often requires the regulator circuit 10 to operate the oscillator/pump in a different manner. This third mode known as the burn-in mode, which is a test mode, often times requires a much different pumped voltage  $V_{ccp}$  than the one used during nominal operation. To compensate for this, the regulator circuit 10 often contains a burn-in transistor 60. The burn-in transistor 60 has its source and drain connected across the source and drain of one of the voltage divider transistors 26. The gate of the burn-in transistor 60 is connected to a burn-in signal line BURNIN. When the memory circuit utilizing the regulator circuit 10 undergoes a burn-in test, the burn-in signal line BURNIN is activated, which activates the burn-in transistor 60. Once activated, the burn-in transistor 60 shunts its corresponding voltage divider transistor 26, which alters the voltage divider circuit 20 and the reference voltage  $V_{ref}$ .

[0015] As can be seen from FIG. 1, the prior art regulator circuit 10 can only shunt one divider transistor 26 during burn-in mode. If a vastly different pumped voltage  $V_{ccp}$  is required for the burn-in test, then the voltage divider and adjustment circuits 20, 40 would require some modifications. This solution is unacceptable because this changes the design of the circuit 10 for nominal operation, which has been designed, tested and qualified as meeting nominal operating mode specifications. Once the design is changed, the part

would have to be re-tested and re-qualified for all modes of operation.

Moreover, the only way to change the design of the circuitry 10 would be to re-mask and re-fabricate it. This would be rather costly with respect to time and money.

5           [0016]   Accordingly, there is a desire and need for a regulator circuit that can adjust the operation of the Vccp pump for different independent modes of operation (e.g., nominal and burn-in modes) that would not require re-designing, re-masking or the re-fabrication of its circuitry.

10           [0017]   Furthermore, manufacturing process variations may render the capability of the burn-in transistor 60, adjustment circuit 40 and voltage divider circuit 20 ineffective for their intended purposes, which could adversely impact the pumped voltage Vccp. Process variations could render one lot of memory circuits different from another lot of memory circuits even though they utilize the same mask, design, etc. This could lead to unexpected variations of the  
15           pumped voltage Vccp. As noted earlier, if Vccp is too high, damage to the memory cells, and higher current may result, if it is too low, the memory chip may have poor data retention or may otherwise operate incorrectly.

20           [0018]   Accordingly, there is a desire and need for a regulator circuit that can adjust the operation of the Vccp pump for different modes of operation that can compensate for process variations.

### SUMMARY OF THE INVENTION

          [0019]   The present invention provides a regulator circuit that can adjust the operation of a voltage pump for different independent modes of operation without re-designing, re-masking or re-fabricating its circuitry.



[0020] The present invention also provides a regulator circuit that can adjust the operation of the voltage pump for different modes of operation that can compensate for process variations.

[0021] The above and other features and advantages are achieved by providing a regulator circuit with at least two independently selectable and adjustable adjustment circuits. Each adjustment circuit is adapted to be connected across a standard voltage divider circuit used to create a reference voltage for operating a voltage pump. Between each adjustment circuit and the voltage divider circuit is an associated connection circuit. Each connection circuit is controlled by an associated control signal. When activated by its respective control signal, the connection circuit connects its associated adjustment circuit to the voltage divider circuit so that the reference voltage is generated by the voltage divider circuit as adjusted by the connected adjustment circuit. Since the amount of adjustment each adjustment circuit can introduce is also independently selectable, the regulator circuit can adjust the operation of the voltage pump for different modes of operation that can compensate for process variations without the need to re-design, re-mask or re-fabricate the circuitry.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The foregoing and other advantages and features of the invention will become more apparent from the detailed description of exemplary embodiments provided below with reference to the accompanying drawings in which:

[0023] FIG. 1 illustrates a conventional pump regulator circuit;

[0024] FIG. 2 illustrates a pump regulator constructed in accordance with an exemplary embodiment of the invention;

[0025] FIG. 3 illustrates a memory circuit incorporating a pump regulator constructed in accordance with an exemplary embodiment of the invention; and

[0026] FIG. 4 illustrates a processor system incorporating a memory circuit constructed in accordance with an exemplary embodiment of the invention.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0027] FIG. 2 illustrates a pump regulator circuit 110 constructed in accordance with an exemplary embodiment of the invention. The regulator circuit 110 includes a step down resistance 12, voltage divider circuit 20, first voltage adjustment circuit 40, second voltage adjustment circuit 140, first connection circuit 160, second connection circuit 180, and a level detect circuit 14. The step down resistance 12 is connected to the pumped voltage Vccp, which is input from a Vccp pump (not shown). The step down resistance 12 is illustrated as a resistor, but it should be appreciated that the resistance 12 could consist of multiple resistors, transistors, diodes, any combinations of these elements or any other circuit element that would cause the pumped voltage Vccp to drop by a specified voltage amount.

[0028] The voltage divider circuit 20 is connected between the step down resistance 12 and another voltage (illustrated as a ground potential). The illustrated voltage divider circuit 20 includes five series connected n-channel MOSFET transistors 22, 24, 26, 28, 30. Each transistor 22, 24, 26, 28, 30 has its gate connected to a voltage such as Vcc such that they are always in the active state. In addition, each transistor 22, 24, 26, 28, 30 is typically a long "L" device that causes a relatively small current draw when activated (i.e., it is well known in the art that the amount of current a MOSFET can carry is proportional

to  $W/L$ , where  $W$  is the width of the transistor and  $L$  is its gate length). Thus, if there were no other elements in the circuit 110, the resistance 12 and the voltage divider circuit 20 would divide the pumped voltage  $V_{ccp}$  in accordance with their resistances and cause a predetermined reference voltage  $V_{ref}$  to appear at node A. It should be noted that the voltage divider circuit 20 may comprise other elements besides the illustrated transistors 22, 24, 26, 28, 30 and it should be appreciated that the circuit 20 could consist of multiple resistors, transistors, diodes, any combinations of these elements or any other circuit element that would create resistance effecting the voltage in a desired manner.

[0029] The reference voltage  $V_{ref}$  is input into the level detect circuit 14. The circuit 14 can be any conventional circuit and thus, the internal circuitry of the circuit 14 is not shown for convenience purposes. As is known in the art, in operation the typical level detect circuit 14 inputs the reference voltage  $V_{ref}$  and compares it to a threshold voltage, which when exceeded, provides a signal to turn on the pump. Similarly, if the reference voltage  $V_{ref}$  is less than the threshold, the circuit 14 provides a signal that turns off the pump. This is typically done by feeding the reference voltage into a modified inverter stage having an adjustable trip point. The trip point is modified with feedback to provide hysteresis for the circuit 14. Subsequent inverter stages provide additional gain and boost the reference voltage signal to the full CMOS level necessary to drive the oscillator. Minimum and maximum operating voltages for the  $V_{ccp}$  pump are controlled by the first inverter stage trip point, hysteresis and diode connected transistors voltages.

[0030] The output of the level detect circuit 14 is a pump on/off signal. The pump on/off signal is used as a control signal for an oscillator 223 (FIG. 3) connected to the  $V_{ccp}$  pump 224. Whenever the pump on/off signal is

set to a value indicating that the Vccp pump should be enabled, the oscillator becomes functional and enables the pump.

[0031] Unlike the prior art regulator circuit 10 (FIG. 1), the regulator circuit 110 of the illustrated embodiment includes two adjustment circuits 40, 140 to adjust the voltage divider circuit 20 so that the proper pump on/off signal can be generated regardless of the Vcc and Vccp voltage levels and, most importantly, regardless of process variations and the variations resulting from age of the circuit 110 -- something the prior art could not do without re-designing, re-masking and re-fabricating the circuit 110 (which also leads to re-qualifying the final product due to the new design).

[0032] The first adjustment circuit 40 includes five n-channel MOSFET transistors 42, 44, 46, 48, 50. Each transistor 42, 44, 46, 48, 50 is connected across a respective voltage divider transistor 22, 24, 26, 28, 30 through connection transistors 162, 164, 166, 168, 170 of the first connection circuit 160. The connection transistors 162, 164, 166, 168, 170 are connected to a first control signal BURNIN.

[0033] If during operation, the first control signal BURNIN has a value that activates the connection transistors 162, 164, 166, 168, 170, the connection transistors 162, 164, 166, 168, 170 connect the adjustment transistors 42, 44, 46, 48, 50 to the voltage divider transistors 22, 24, 26, 28 and 30. That is, the first connection circuit 160 connects the first adjustment circuit 40 to the voltage divider circuit 20. If during operation, the first control signal BURNIN has a value that does not activate the connection transistors 162, 164, 166, 168, 170, the connection transistors 162, 164, 166, 168, 170 disconnect the adjustment transistors 42, 44, 46, 48, 50 from the voltage divider transistors 22, 24, 26, 28 and 30. That is, the first connection circuit 160 disconnects the first adjustment circuit 40 from the voltage divider circuit 20. It

should be noted that the first control signal BURNIN may be generated by a test key or any other device or in any manner known in the art and that the exact method of doing so is not relevant to practice the invention.

[0034] Unlike the gate terminals of the voltage divider transistor 22, 24, 26, 28, 30, the gate terminals of the adjustment transistors 42, 44, 46, 48, 50 do not have to be connected such that they are always in the active state. Instead, the gate of each adjustment transistor 42, 44, 46, 48, 50 can be connected such that the transistor 42, 44, 46, 48, 50 is active or inactive. For the following example, it is presumed that the first control signal BURNIN is in the state that activates the connection transistors 162, 164, 166, 168, 170, and thus, connects the adjustment transistors 42, 44, 46, 48, 50 to the voltage divider transistors 22, 24, 26, 28, 30. For example, in FIG. 2, the fourth and fifth adjustment transistors 48, 50 are connected to a voltage such as  $V_{cc}$ , which activates both transistors 48, 50. With both of these adjustment transistors 48, 50 in the active state, their corresponding voltage divider transistors 28, 30 are shunted. This, removes the resistances associated with the fourth and fifth voltage divider transistors 28, 30, which changes the voltage divider circuit 20 and alters the voltage level of the reference voltage  $V_{ref}$ . Thus, the adjustment transistors 48, 50 act as switches that can switch in or out (i.e., do not shunt or shunt) the resistance associated with their corresponding voltage divider transistors 28, 30.

[0035] As noted above, the other adjustment transistors 42, 44, 46 do not have to be connected such that they are always in the active state. For example, the first three adjustment transistors 42, 44, 46 are connected to two signal lines OPT1, OPT2. The signal lines OPT1, OPT2 can be set by test keys or fuses such that their respective adjustment transistors 42, 44, 46 are active or inactive. If any of these adjustment transistors 42, 44, 46 are set to the active state, then

their corresponding divider transistor 22, 24, 26 will be shunted. Likewise, if any of the first three adjustment transistors 42, 44, 46 are set to the inactive state, then their corresponding divider transistor 22, 24, 26 will not be shunted. Thus, for the illustrated regulator circuit 110, depending on how the signal lines OPT1, OPT2 are set, the voltage divider circuit 20 may include none, all three or some of the first three divider transistors 22, 24, 26 (i.e., in FIG 1 the fourth and fifth divider transistors 28, 30 have already been shunted and thus, only the first three divider transistors 22, 24, 26 can add resistance to the divider circuit 20) when the first control signal BURNIN is in a state that activates the connection transistors 162, 164, 166, 168, 170, causing adjustment transistors 42, 44, 46, 48, 50 to be connected to the voltage divider transistors 22, 24, 26, 28, 30.

[0036] Similarly, the second adjustment circuit 140 includes five n-channel MOSFET transistors 142, 144, 146, 148, 150. Each transistor 142, 144, 146, 148, 150 is connected across a respective voltage divider transistor 22, 24, 26, 28, 30 through connection transistors 182, 184, 186, 188, 190 of the second connection circuit 180. The connection transistors 182, 184, 186, 188, 190 are connected to a second control signal BURNIN\_.

[0037] If during operation, the second control signal BURNIN\_ has a value that activates the connection transistors 182, 184, 186, 188, 190, the connection transistors 182, 184, 186, 188, 190 connect the adjustment transistors 142, 144, 146, 148, 150 to the voltage divider transistors 22, 24, 26, 28 and 30. Thus, the second connection circuit 180 connects the second adjustment circuit 140 to the voltage divider circuit 20. If during operation, the second control signal BURNIN\_ has a value that does not activate the connection transistors 182, 184, 186, 188, 190, the connection transistors 182, 184, 186, 188, 190 disconnect the adjustment transistors 142, 144, 146, 148,

150 from the voltage divider transistors 22, 24, 26, 28, 30. Thus, the second connection circuit 180 disconnects the second adjustment circuit 140 from the voltage divider circuit 20. It should be noted that the second control signal BURNIN\_ may be generated by a test key or any other device or in any manner known in the art and that the exact method of doing so is not relevant to practice the invention.

[0038] Unlike the gate terminals of the voltage divider transistor 22, 24, 26, 28, 30, the gate terminals of the adjustment transistors 142, 144, 146, 148, 150 do not have to be connected such that they are always in the active state. Instead, the gate of each adjustment transistor 142, 144, 146, 148, 150 can be connected such that the transistor 142, 144, 146, 148, 150 is active or inactive. For the following example, it is presumed that the second control signal BURNIN\_ is in the state that activates the connection transistors 182, 184, 186, 188, 190, and thus, the connection transistors 182, 184, 186, 188, 190 connect the adjustment transistors 142, 144, 146, 148, 150 to the voltage divider transistors 22, 24, 26, 28, 30. For example, in FIG. 2, the second adjustment transistors 144 is connected to a ground potential, which permanently deactivates transistors 144. Thus, the associated voltage divider transistor 24 will not be shunted when the second adjustment circuit 140 is connected to the voltage divider circuit 20 by the second connection circuit 180. This, means that the resistance associated with the second voltage divider transistor 24 will remain in the voltage divider circuit 20.

[0039] In FIG. 2, the first and third adjustment transistors 142, 146 of the second adjustment circuit 140 are connected to the same signal line OPT1 while the fourth and fifth adjustment transistors 148, 150 of the second adjustment circuit 140 are connected to the a second signal line OPT2. The signal lines OPT1, OPT2 can be set by test keys or fuses such that their

respective adjustment transistors 142, 146, 148, 150 are active or inactive. If any of these adjustment transistors 142, 146, 148, 150 are set to the active state, then their corresponding divider transistor 22, 26, 28, 30 will be shunted.

Likewise, if any of these adjustment transistors 142, 146, 148, 150 are set to the inactive state, then their corresponding divider transistor 22, 26, 28, 30 will not be shunted. Thus, for the illustrated regulator circuit 110, depending on how the signal lines OPT1, OPT2 are set, the voltage divider circuit 20 will include the second voltage divider transistor 24 and may include none, all four or some of the first, third, fourth and fifth divider transistors 22, 26, 28, 30 when the second control signal BURNIN\_ is in a state that activates the connection transistors 182, 184, 186, 188, 190, causing adjustment transistors 142, 144, 146, 148, 150 to be connected to the voltage divider transistors 22, 24, 26, 28, 30.

[0040] Typical operating modes for a system incorporating the regulator circuit 110 of the invention include power-up, nominal and burn-in modes. By connecting one of the adjustment circuits 40, 140 to the voltage divider 20 via the connection circuits 160, 180, or disconnecting both of the adjustment circuits 40, 140 from the voltage divider 20, the regulator circuit 110 can be independently adjusted for any of these modes. Moreover, each adjustment circuit 40, 140 can be adjusted such that they switch in or out (i.e., do not shunt or shunt) specific resistances from the voltage divider circuit 10. This way, variations due to process variations can be compensated for without the need to re-design, re-mask, re-fabricate and re-qualify the circuitry.

[0041] To be consistent with the prior art regulator circuit 10 (FIG. 1) the first control signal illustrated in FIG. 2 is labeled BURNIN while the second control signal is labeled BURNIN\_ to represent burn-in and non-burn-in modes, respectively. It should be appreciated, however, that these signals can represent



any desired mode of operation, e.g., power-up, and do not have to be tied to the burn-in mode of operation. Furthermore, it should be appreciated that the voltage divider 20 could contain more or less voltage divider transistors 22, 24, 26, 28, 30, which could alter the number of transistors used in the adjustment circuits 40, 140 and the connection circuit 160, 180, if so desired. Thus, the invention is not to be limited to the number of transistors used in any of these circuits 20, 40, 140, 160, 180.

[0042] FIG. 3 illustrates a memory circuit 200 incorporating a regulator circuit 110 constructed in accordance with an embodiment of the invention. Thus, the memory circuit 200 will be capable of adjusting the pumped voltage  $V_{ccp}$  for multiple modes of operation (e.g., nominal and burn-in modes) in accordance with the present invention. A conventional power supply 240 provides regulated power signals to a memory array 210 and its related memory access circuits. These power signals may include  $V_{cc}$  (i.e., the primary operating voltage for the circuit 200) and  $V_{bb}$  (i.e., the voltage level to which the substrate voltage is regulated).

[0043] The memory array 210 consists of a number of individual memory cells or transistors organized in rows and columns. As known in the art, each memory cell can hold one of two states, corresponding to binary zero and binary one. For a data access (read or write) operation to be performed upon a particular memory cell within the array 210, a read/write control circuit 212 provides the row address of the cell to a row decoder 216 and the column address of the cell to a column decoder 214. Data in/out buffers 218 are used provide an interface for the data between the selected memory cell and external data (input/output) ports (not shown), which are coupled to the buffers 218.

[0044] A sense amplifier circuit 220, which is also controlled in part by the read/write control circuit 212, is used to convert the information provided

by the selected memory cell to the appropriate voltage level for the data in/out buffer 218. Control over the timing and direction of data flow is provided by the read/write control circuit 212. Each of the above circuits is well known in the art and do not require further discussion.

5           [0045] To ensure accurate and fast access to the selected memory cells, a stable high-level pumped voltage  $V_{ccp}$  is provided to the memory array 210 at a voltage level which is greater than  $V_{cc}$ . In a typical DRAM application, the voltage for  $V_{cc}$  may be set to about 2.5 volts, thereby requiring the pumped voltage  $V_{ccp}$  to be set so as to safely operate more than one diode drop higher than  $V_{cc}$ . For example, if  $V_{cc}$  is set at 2.5 volts, setting  $V_{ccp}$  to approximately 10           4.0 volts would be an acceptable design criteria. As noted above, the purpose of the regulator 110 and the  $V_{ccp}$  pump circuit 224 (including oscillator 223) is to provide the pumped voltage  $V_{ccp}$  at such a regulated level. In addition, the regulator 110 of the invention can adjust the pumped voltage  $V_{ccp}$  for other 15           operating modes (e.g., burn-in) in a manner that can compensate for process variations, etc. and which does not require mask changes or re-qualification of the completed memory circuit 200. It should be noted that the  $V_{ccp}$  pump circuit 224 is conventional and may be implemented using any of a number of circuits.

20           [0046] FIG. 4 illustrates a processor system 300 incorporating a memory circuit 200 constructed in accordance with an embodiment of the invention. That is, the memory circuit 200 may be configured as shown in FIG. 3 and may utilize the regulator circuit 110 illustrated in FIG. 2. The system 300 may be a computer system, a process control system or any other system 25           employing a processor and associated memory.

          [0047] The system 300 includes a central processing unit (CPU) 302, e.g., a microprocessor, that communicates with the memory circuit 200 and an

I/O device 308 over a bus 320. It must be noted that the bus 320 may be a series of buses and bridges commonly used in a processor system, but for convenience purposes only, the bus 320 has been illustrated as a single bus. A second I/O device 310 is illustrated, but is not necessary to practice the invention. The system 300 may also include additional memory devices such as a read-only memory (ROM) device 312, and peripheral devices such as a floppy disk drive 304 and a compact disk (CD) ROM drive 306 that also communicates with the CPU 302 over the bus 320 as is well known in the art. It should be noted that the memory 200 may be embedded on the same chip as the CPU 302 if so desired.

[0048] While the invention has been described and illustrated with reference to exemplary embodiments, many variations can be made and equivalents substituted without departing from the spirit or scope of the invention. Accordingly, the invention is not to be understood as being limited by the foregoing description, but is only limited by the scope of the appended claims.

[0049] What is claimed as new and desired to be protected by Letters Patent of the United States is: